

#245

ALOUETTE 1 62-049A-01Q

ALOUETTE 2 65-098A-01N

ISIS 1 69-009A-01E

ISIS 2 71-024A-01E

INDEX OF DUCTED ECHOES

ALOUETTE 1        62-049A-010  
ALOUETTE 2        65-098A-01N  
ISIS 1            69-009A-01E  
ISIS 2            71-024A-01E

CRC INDEX OF DUCTED ECHOES

ARC N(H) INT. PROFILES

THIS DATA SET HAS BEEN RESTORED. THERE WAS ORIGINALLY ONE 9-TRACK, 800 BPI TAPE, WRITTEN IN EBCDIC. THERE IS ONE RESTORED TAPE. THE DR TAPE IS A 3480 CARTRIDGE AND THE DS TAPE IS 9-TRACK, 6250 BPI. THE ORGINAL TAPE WAS CREATED ON AN IBM 360 COMPUTER. THE DR AND DS NUMBERS ALONG WITH THE CORRESPONDING D NUMBER AND TIME SPAN IS AS FOLLOWS

DR#	DS#	DD#	FILES	TIME SPAN
DR002716	DS002716	D012316	1	12/01/62 - 12/31/68

\*I/O ERROR ON RECORD #2911

REQ. AGENT  
WTJ

RASH NO.  
RB4544

ACQ. AGENT  
LLD

INDEX OF DUCTED ECHOES

ALOUETTE 1 62-049A-01Q

ALOUETTE 2 65-098A-01N

ISIS 1 69-009A-01E

ISIS 2 71-024A-01E

These data sets contained on 1 800 BPI, EBCDIC, 9-track tape that was produced on an IBM 360 computer. The data is contained in 1 file where each satellite is distinguished by a satellite number found in character position 1-2.

D-12316

C-09639

<u>SATELLITE</u>	<u>START</u>	<u>STOP</u>
ALOUETTE 1	12/01/62	12/31/68
ALOUETTE 2	11/29/65	10/30/71
ISIS 1	02/01/69	12/27/71
ISIS 2	04/09/71	06/22/72

## CONJUGATE ECHO DATA

Conjugate echo data scaled from Topside Sounder Ionograms recorded by Satellites Alouette 1 & 2 and ISIS 1 & 2 are available on a digital magnetic tape. The very first record on the tape is a 42 character record containing English language text describing the contents of the tape.

The data (after first record) have the format described below:

<u>CHARACTER POSITION</u>	<u>FORMAT</u>	<u>DESCRIPTION</u>
1-2	I2	Satellite number 1 (Alouette 1) 2 (Alouette 2) 3 (ISIS 1) 4 (ISIS 2)
3-5	I3	Station number
6-8	I3	Year
9-12	I4	Day number
13-17	I5	Hours and minutes (GMT) (Beginning of Pass)
18-20	I3	Number of ionograms with ducted echoes
21-23	I3	Number of ionograms without ducted echoes

### Number of Records for Individual Satellites:-

<u>SATELLITE</u>	<u>NUMBER OF RECORDS (PASSES)</u>	5	8	3	21	48
Alouette 1	209	62-65, 67-68				
Alouette 2	4452	65-68	65-68	65-67	65-68	65-68
ISIS 1	3050	69-71	69-71	69-71	69-71	69-71
ISIS 2	524	71-72				
<u>TOTAL</u> Records on Tape	<u>8235</u>					71

**DATA USERS' NOTE**

NSSDC 67-29

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B05106-000A

**ALOUETTE 1 (1962 BETA ALPHA 1)**  
**TOPSIDE SOUNDER**

**JULY 1967**



**NATIONAL SPACE SCIENCE DATA CENTER**

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • GODDARD SPACE FLIGHT CENTER, GREENBELT, MD.

DATA USERS' NOTE  
NSSDC 67-29

ALOUETTE 1 (1962 BETA ALPHA 1)  
TOPSIDE SOUNDER

INVESTIGATORS

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JULY 1967

## FOREWORD

This Data Users' Note is specifically designed to help potential data users decide if they can make use of the data obtained in the Alouette 1 (1962 Beta Alpha 1) topside sounder experiment. Once a data user decides that he requires the data, it will serve as the unifying element - the key - in the actual use of the data available at the National Space Science Data Center (NSSDC). To achieve these goals, the Note briefly describes the experiment, including the instrumentation and measurements, the telemetry, and the operational experience. All available details are then provided on the actual reduction techniques and format of recorded data. For those desiring more details, names and addresses of the investigators are provided to facilitate direct contact. As a further aid, detailed references (and bibliography) are also included. When available, NASA accession numbers\* are given. The primary purpose of these references is to identify the sources containing complete information concerning the subject under discussion. Most of these references are physically available at NSSDC - those that are not are readily obtainable.

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\*For example, N64-2243 is an accession number for an article reported in the *Scientific and Technical Aerospace Reports* (STAR), and A63-5921 refers to an entry in the *International Aerospace Abstracts* (IAA).

## CONTENTS

	<u>Page</u>
<b>BACKGROUND . . . . .</b>	1
<b>INVESTIGATORS . . . . .</b>	1
<b>EXPERIMENT . . . . .</b>	1
Instrumentation and Measurements . . . . .	1
Telemetry . . . . .	3
Operational Experience . . . . .	3
<b>DATA . . . . .</b>	5
Introductory Remarks . . . . .	5
A - Ionograms . . . . .	6
B - Alosyn . . . . .	16
C - Synoptic Data . . . . .	19
D - Electron Density vs Real Height . . . . .	21
E - Electron Density Profiles . . . . .	25
F - Electron Density and Scale Height vs Real Height . . . . .	29
<b>REFERENCES . . . . .</b>	35
<b>BIBLIOGRAPHY . . . . .</b>	37

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Alouette 1 Experiments . . . . .	2
2	Location and Coverage of Alouette 1 Telemetry Stations . . . . .	4
3	Sample of Typical Ionogram . . . . .	7
4	DRTE Binary Dot Coding - Horizontal Display . . . . .	8
5	DRTE Binary Dot Coding - Vertical Display . . . . .	9
6	DRTE Binary Digital Coding . . . . .	10
7	Numerical Time Coding . . . . .	11
8	Code List for Alouette Telemetry Stations . . . . .	13
9	Terms Used in Remarks on Film Log Sheet . . . . .	14
10	Ionogram Times and Stations . . . . .	15
11	Alosyn Data (DRTE) . . . . .	17

<u>Figure</u>		<u>Page</u>
12	Description of Topside Sounder Catalog Listing (ITSA) . . . . .	20
13	Telemetry Station Code and Location (ITSA) . . . . .	21
14	Alouette 1 Real Height Profiles (DRTE) . . . . .	23
15	Stations and Times for Selected Ionograms (ITSA, RSRS) . . . . .	26
16	Sample of RSRS Data . . . . .	28
17	Sample of Electron Density and Scale Height Data vs Real Height (ARC) . . . . .	33

## ALOUETTE 1 (1962 BETA ALPHA 1) TOPSIDE SOUNDER

### BACKGROUND

The Alouette 1 topside sounder satellite was launched on September 29, 1962, from the Pacific Missile Range. The Canadian Defence Research Telecommunications Establishment (DRTE) of Ottawa, Canada, proposed and constructed the satellite in cooperation with NASA. The orbital period of Alouette 1 was 105.5 min and the inclination was 80.5 deg to the equatorial plane. The spacecraft achieved a nearly circular orbit having an apogee of approximately 1030 km and a perigee of 998 km.<sup>1,2</sup>

The topside sounder instrumentation was one of the four experiments on Alouette 1, as shown in Figure 1. The primary data collected from the topside sounder underwent several different methods of reduction by DRTE scientists, as well as by scientists at Ames Research Center (ARC), Goddard Space Flight Center (GSFC), the Institute for Telecommunication Sciences and Aeronomy (ITSA), and the Radio and Space Research Station (RSRS). These data are grouped according to the arrangement shown in Figure 1.

### INVESTIGATORS

G. L. B. Nelms - Defence Radio Telecommunications Establishment\*  
E. Warren - Defence Radio Telecommunications Establishment\*  
R. Fitzenreiter - Goddard Space Flight Center\*\*  
J. E. Jackson - Goddard Space Flight Center\*\*

See the "Data" section for the names and current addresses of other investigators.

### EXPERIMENT

#### Instrumentation and Measurements

The topside sounding technique used in Alouette 1 was an extension of the sounding method used for routine ionospheric sounding observations from the ground. In general, this equipment consists of a low frequency radar system

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\*Address: Defence Radio Telecommunications Establishment, Shirley Bay, Ottawa 4, Ontario, Canada.

\*\*Address: Goddard Space Flight Center, Code 615, Greenbelt, Maryland 20771.

FIGURE 1  
ALOUETTE 1 EXPERIMENTS

No.	Experiment	Investigator(s)	Affiliation
01	Topside Sounder	G. L. B. Nelms E. Warren R. Fitzenreiter J. Jackson	DRTE <sup>a</sup> DRTE <sup>a</sup> GSFC <sup>b</sup> GSFC <sup>b</sup>
	A - Ionograms (Primary Data)	G. L. B. Nelms	DRTE <sup>a</sup>
	B - Alosyn	E. L. Hagg	DRTE <sup>a</sup>
	C - Synoptic Data	W. Calvert	ITSA <sup>c</sup>
	D - Electron (Number) Density Profiles	G. L. B. Nelms G. E. K. Lockwood	DRTE <sup>a</sup> DRTE <sup>a</sup>
	E - Electron Density Profiles	W. Calvert T. E. Van Zandt J. W. King	ITSA <sup>c</sup> ITSA <sup>c</sup> RSRS <sup>d</sup>
	F - Electron Density Profiles and Scale Height Profiles	J. O. Thomas M. J. Rycroft L. Colin K-L. Chan	ARC <sup>e</sup> ARC <sup>e</sup> ARC <sup>e</sup> ARC <sup>e</sup>
02	Energetic Particle Counters	D. C. Rose I. B. McDiarmid	NRC <sup>f</sup> NRC <sup>f</sup>
03	VLF Receiver	J. S. Belrose R. Barrington	DRTE <sup>a</sup> DRTE <sup>a</sup>
04	Cosmic Noise	T. R. Hartz	DRTE <sup>a</sup>

a - Defence Research Telecommunications Establishment (Canada)

b - Goddard Space Flight Center

c - Institute for Telecommunication Sciences and Aeronomy (formerly known as Central Radio Propagation Laboratories, CRPL)

d - Radio and Space Research Station (formerly known as Radio Research Station, Great Britain)

e - Ames Research Center

f - National Research Council (Canada)

NOTE: Some of the affiliations have changed since the time of the Alouette 1 experiments. Current addresses are provided in the descriptions of the individual data sets.

in which the carrier frequency is swept from 1 Mc/s to about 20 Mc/s. The transmitted Ordinary wave signals propagate downward in the ionosphere and are subsequently reflected when they reach a region of electron density, N, which is given by<sup>3</sup>

$$N = 1.2388 \times 10^4 f^2$$

where

N = electron density per cm<sup>3</sup>, and

f = frequency in Mc/s of the Ordinary ray<sup>†</sup>

The topside sounding instrument in Alouette 1 is basically a pulsed transmitter and receiver tuned to the transmitter wave frequency in order to obtain echo returns from the ionosphere. The wave frequency is continuously varied from 0.5 to 11.5 Mc/s at a rate of 1 Mc/s<sup>2</sup>. The time required for one complete sweep is approximately 12 sec, during which time the satellite traveled a distance of about 80 km. The time interval between ionograms is about 18 sec, which corresponds to a distance of about 125 km.<sup>3</sup>

### Telemetry

The output of the receiver was telemetered to the ground via a two-watt transmitter which operated in the 136-Mc/s band. The system operated on command from the ground, obtaining and telemetering data for a 10-min period after which it turned off automatically.

The telemetry signals were recorded on magnetic tape and were subsequently transcribed onto 35-mm film. In this manner, a photographic record was provided showing the variation of the virtual depth of reflection beneath the satellite, P', as a function of the frequency, f, of the transmitted radio waves.<sup>1</sup>

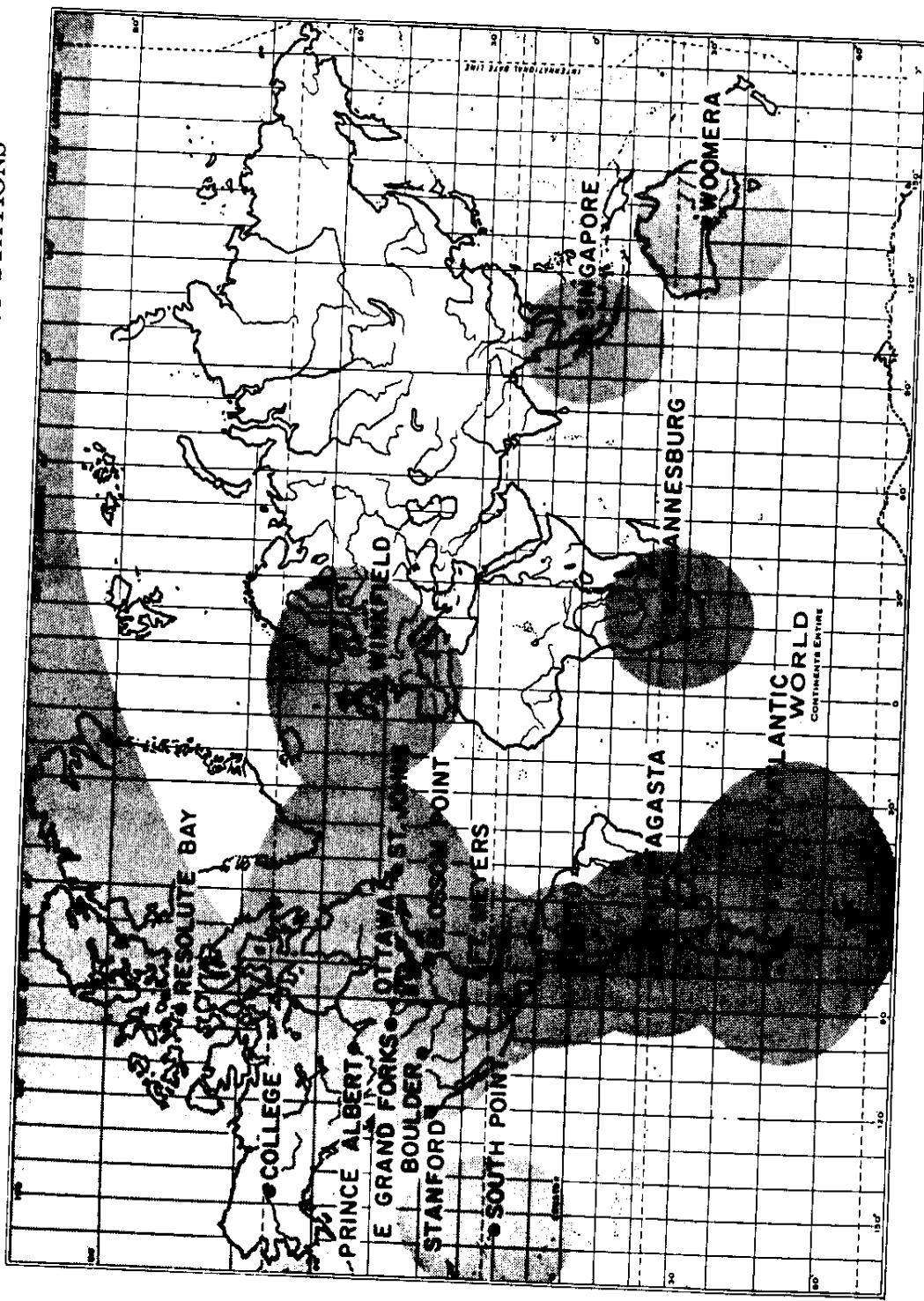
### Operational Experience

The Alouette tracking stations, as shown in Figure 2, are situated in locations which provided for successive monitoring from 80°N to 80°S.<sup>4</sup> Since the satellite orbit rotated only 0.99° per day, three months were required to sample all local times at the equator.<sup>5</sup> Ionograms are still being recorded at the time of publication of this Note.

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<sup>†</sup>By agreement, all investigators use  $1.24 \times 10^4$  as the multiplicative constant.

FIGURE 2  
LOCATION AND COVERAGE OF ALOUETTE 1 TELEMETRY STATIONS



## DATA

### Introductory Remarks

As stated earlier in this Note, the variable depths of reflection below the satellite,  $P'$ , of radio pulses vertically incident on the topside ionosphere were measured as a function of frequency,  $f$ . The frames of 35-mm film showed traces of the  $P'(f)$  data. From these traces, or ionograms, various methods of data reduction were used to obtain the data sets listed in Figure 1.

The virtual depth of reflection below the satellite,  $P'$ , is defined by  $P' = 1/2 ct$ , where  $c$  is the speed of light and  $t$  is the travel time. Since the radio pulse did not travel in a vacuum, but in a plasma, the actual distance traveled differed from the virtual depth. If  $h$  is the real depth of reflection below the satellite, then for the Extraordinary trace:

$$P'(f) = \int_{f_{os}}^{f_{Nr}} M' \frac{dh}{df_N} df_N$$

where

$f$  = the measured Extraordinary wave frequency on the ionogram trace

$f_{Nr} = (f^2 - ff_H)^{1/2}$  = plasma frequency at the reflection point

$f_H$  = the gyrofrequency for an electron in the earth's magnetic field for the position corresponding to  $h$

$f_{os} = (f_{xs}^2 - f_{xs} f_{Hs})^{1/2}$  where the  $s$  denotes the frequencies at the position of the satellite.  $f_{os}$  is the plasma frequency at the satellite.

$f_{xs}$  = the frequency at which the Extraordinary trace had zero range

$M'$  = the group refractive index of the Extraordinary ray, which may be calculated from the Appleton-Hartree Magneto-ionic equation, and,

$f_N$  = the plasma frequency (considered as a variable dependent upon the altitude).<sup>1</sup>

The following pages include a brief description of the primary data set (ionograms) and the derived data sets, as well as a summary of the reduction techniques involved for each set. These descriptions are arranged in the order in which they appear in Figure 1.

## A - Ionograms

### Investigator

G. L. B. Nelms - Defence Radio Telecommunications Establishment

The Alouette ionograms exhibit plasma resonances, echoes from Ordinary, Extraordinary and Z plasma modes, and echoes from below the F2 maximum atmospheric layer reflections. The ionograms, on 35-mm film, were directly recorded from the analog record. The analog record contained time, frequency versus virtual depth signals, and frequency markers. These markers occurred at 0.5, 1.5, 2.0, 2.5, 3.5, and 7.0 Mc/s and were generated on board the satellite. The vertical lines, showing frequency (see sample in Figure 3), were constructed from the frequency markers at the time of filming.

The frequency lines began at any point and moved downward to the bottom of the ionogram, and once again moved from top to bottom. The beginning point, or the left extreme of the frequency lines, gives the exact frequency values as shown in Figure 3.

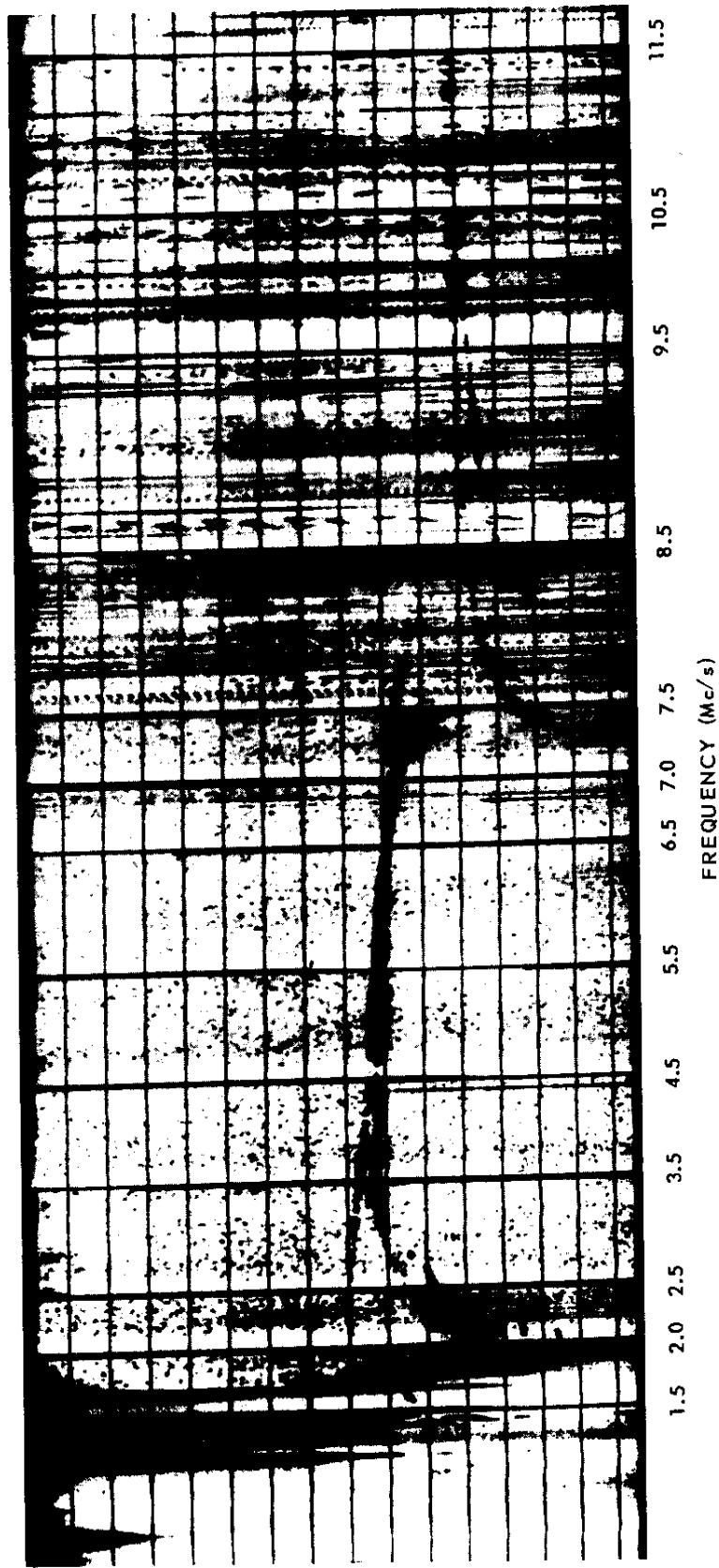
Several methods of time coding appear on the filmed ionograms. These are shown in Figures 4-7.\* In each of these figures, an actual photograph of an ionogram containing a certain type of code is shown along with a schematic representation of the coded ionogram. Figure 4 shows a Horizontal Binary Dot Coding. The time code is represented along the lower edge of the ionogram in binary code. The code is formed by representing each character by a vertical grouping of dots representing various powers of 2 with decreasing magnitude found in the forward direction. The code beds are located as follows:

the first three vertical dot groupings representing the day,  
the fourth and fifth groupings representing the hour,  
the sixth and seventh representing the minutes,  
the eighth and ninth representing the seconds, and  
the tenth and last vertical group of dots representing the station number.

Figure 5 illustrates a display of Vertical Binary Dot Coding. This system of coding is identical to the horizontal coding except that the code groupings run vertically upward from the bottom left of the ionogram. This code is most easily read with the ionograms in the vertical position with the frequency markers

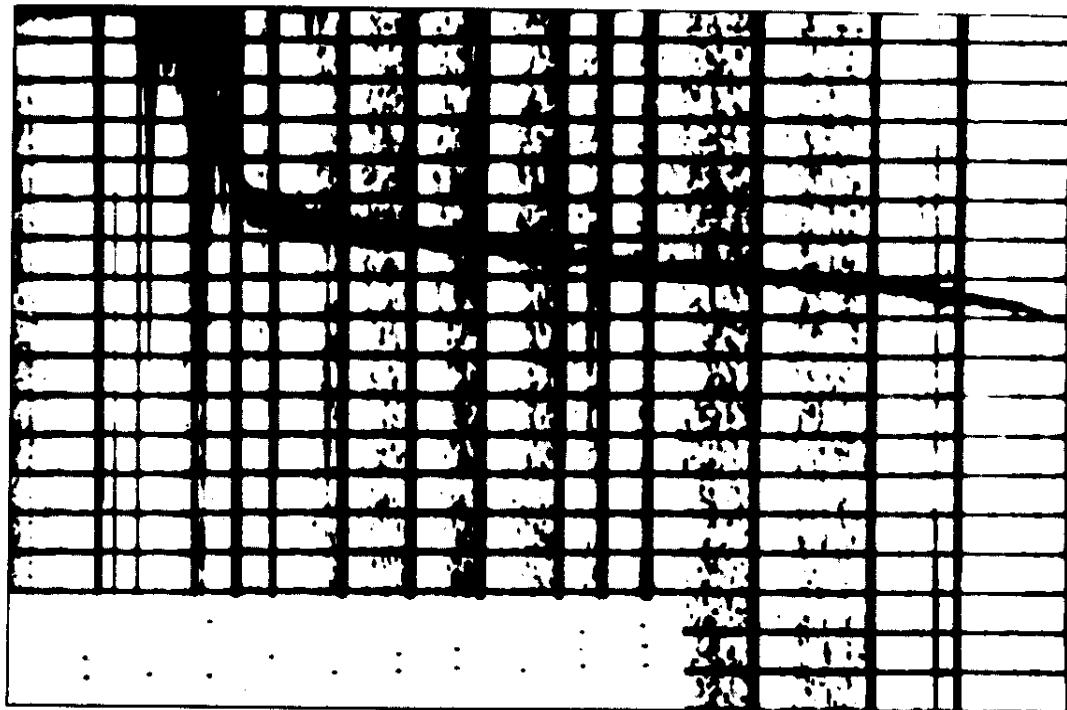
\*At times, the identification is not complete. For example, Figures 4 and 5 do not indicate the year—complete identification can be obtained from the film log sheets.

FIGURE 3  
SAMPLE OF TYPICAL IONOGRAM



NOTE: The frequency lines and lines of virtual depth are not labelled on the 35-mm frames. The lines have essentially the same values on all frames.

FIGURE 4  
DRTE BINARY DOT CODING - HORIZONTAL DISPLAY



ACTUAL IONGRAM

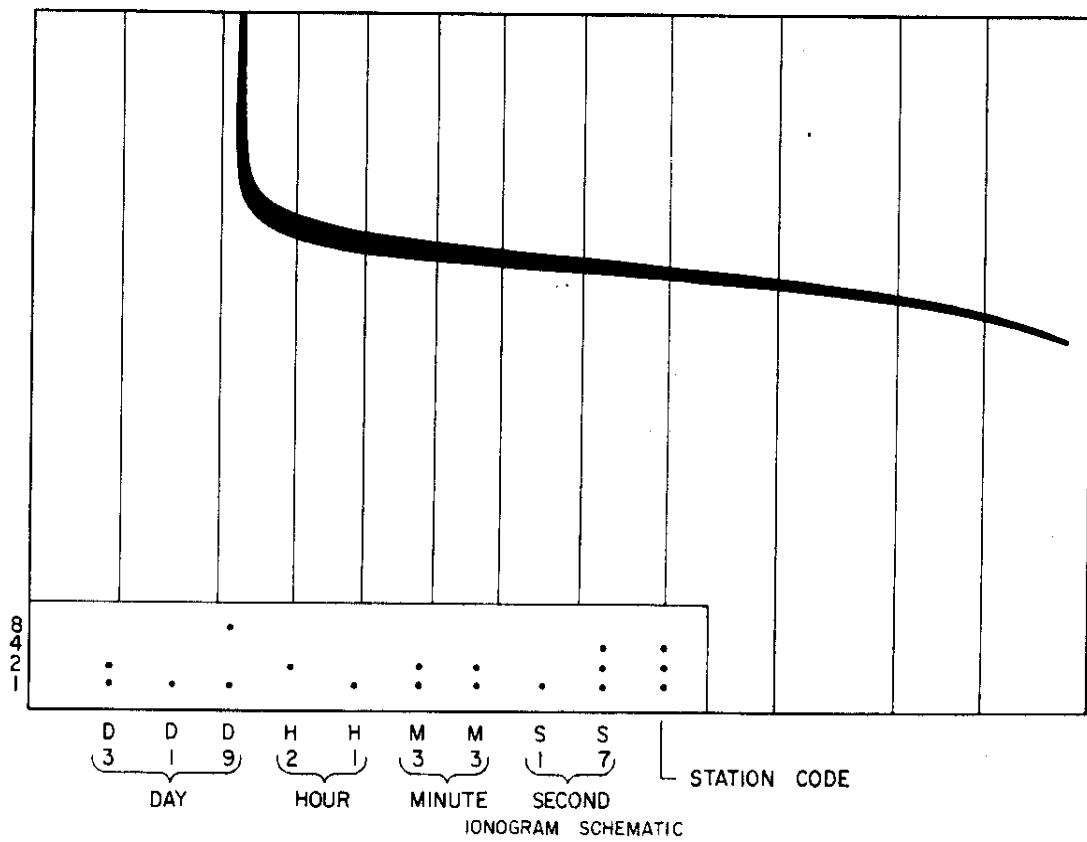
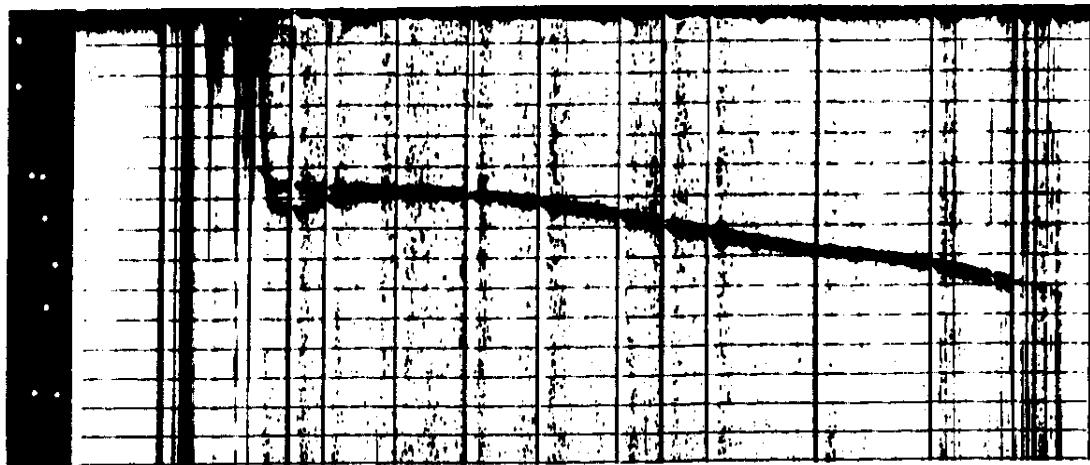
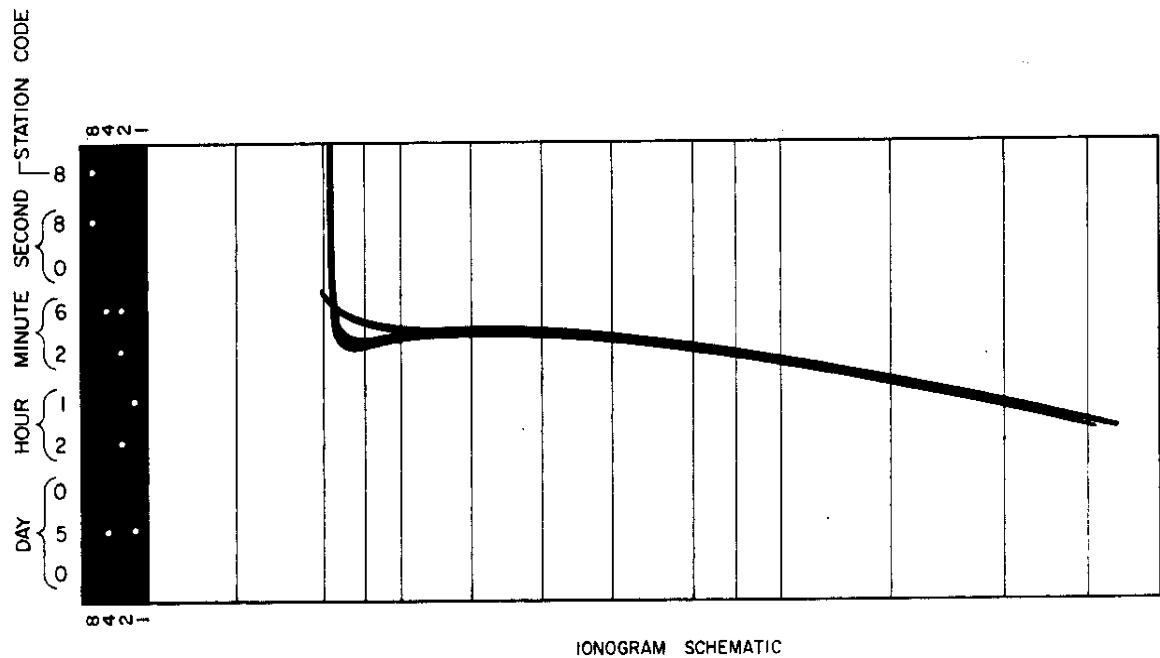


FIGURE 5  
DRTE BINARY DOT CODING - VERTICAL DISPLAY

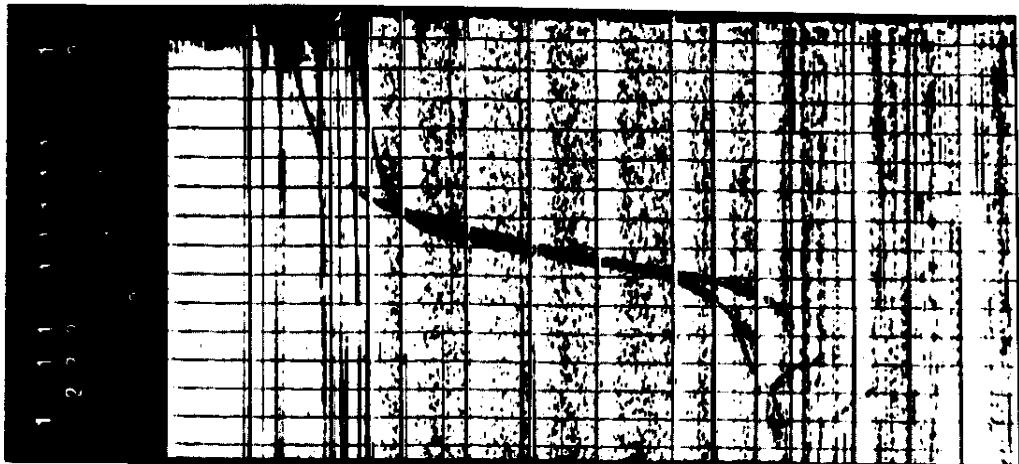


ACTUAL IONGRAM

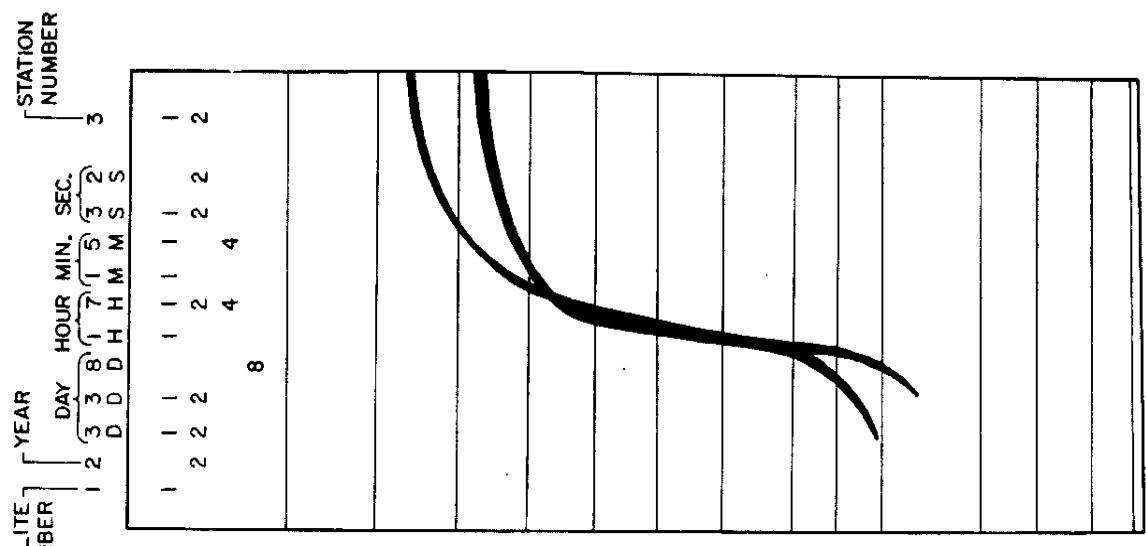


IONGRAM SCHEMATIC

**FIGURE 6**  
**DRTE BINARY DIGITAL CODING**

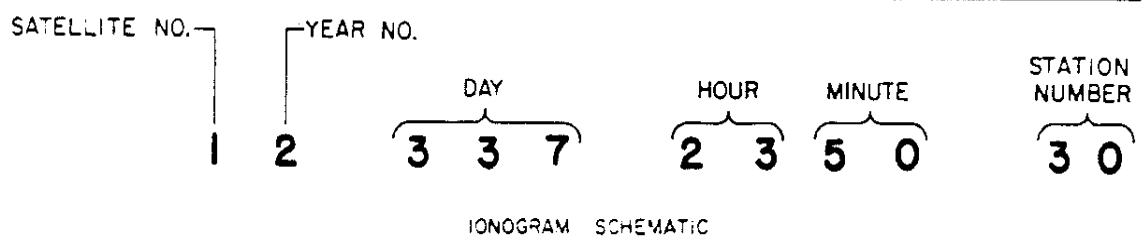
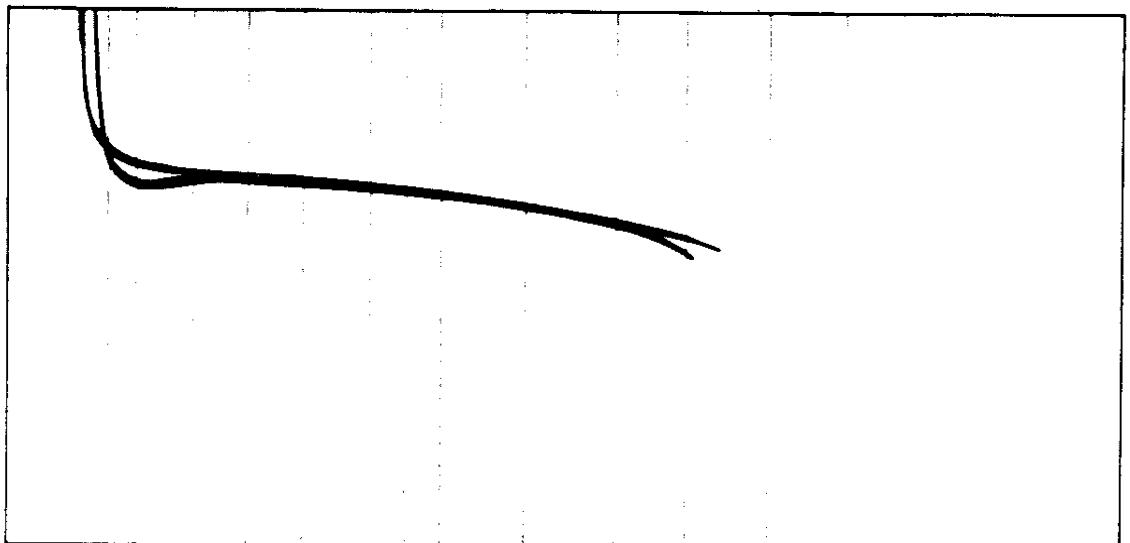
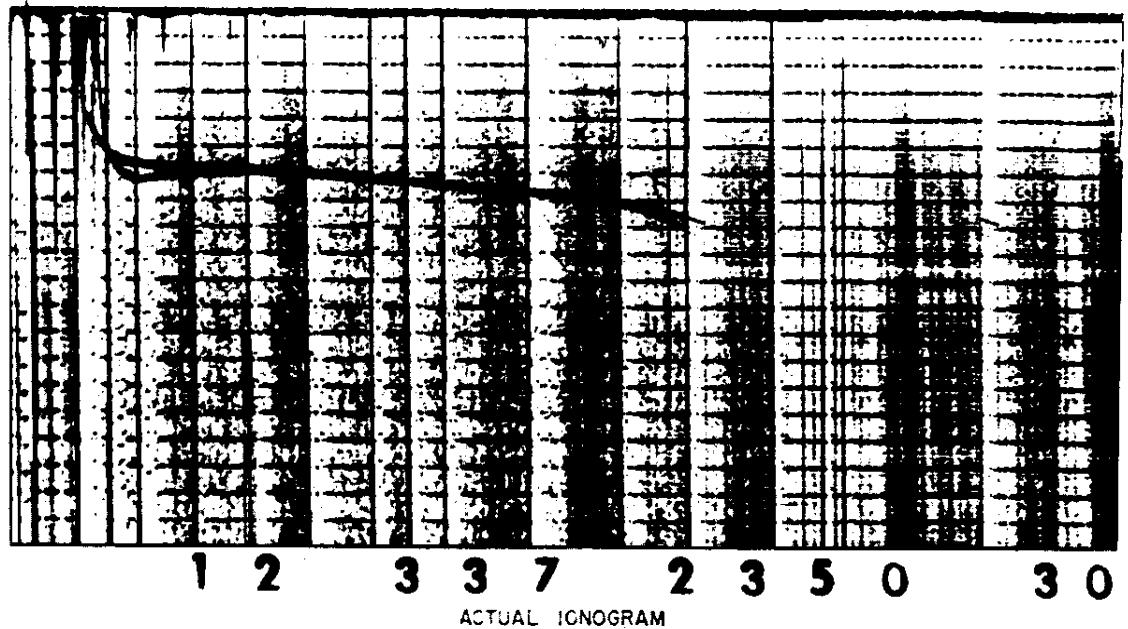


**ACTUAL IONOGRAM**



IONOGRAM SCHEMATIC

FIGURE 7  
NUMERICAL TIME CODING



increasing in the downward direction. The code is then read with the significance of binary code beds from left to right as follows:

the first three vertical groupings representing the day,  
the fourth and fifth groupings representing the hour,  
the sixth and seventh representing the minutes,  
the eighth and ninth representing the seconds, and  
the tenth representing the station code.

When the ionogram is held in the vertical position, the higher powers of two are at the top.

A third method of time coding, shown in Figure 6, is the Binary Digital Coding. This is a vertical display in which arabic numerals are used instead of dots and two extra code groupings are added to give the satellite number and last digit of the year. The coding is located on the left edge of the ionogram and is best read with the numerals in the upright position. The sum of the digits in each vertical code grouping gives the number to be represented. The significance of the code groupings running from left to right is as follows:

the first group gives the satellite number,  
the second group gives the last digit of the year,  
the third, fourth, and fifth groups give the days since the start of the year,  
the sixth and seventh groupings give the hours,  
the eighth and ninth groupings give the minutes,  
the tenth and eleventh groupings give the seconds, and  
the twelfth and thirteenth groupings give the station number.

An additional Numerical Time Coding is given in Figure 7. This code is printed in arabic numerals at the bottom of the ionogram. The significance of the numerals from left to right is as follows:

the first digit is the satellite number,  
the second is the last digit of the year,  
the third, fourth, and fifth digits are the days of the year,  
the sixth and seventh are the hours,  
the eighth and ninth are the minutes, and  
the last digits are the station code.

The Alouette telemetry station code list is given in Figure 8. The station number, three-letter code, and geographic latitude and longitude are included for each station.

FIGURE 8  
CODE LIST FOR ALOUETTE TELEMETRY STATIONS

STATION NAME	STATION NUMBER	3-LETTER CODE	GEOGRAPHIC LAT.	LONG.
Antofagasta, Chile	8*	ANT	23.6S	70.3W
Blossom Point, Maryland	14*, 1	BPT	38.4N	77.1W
Boulder, Colorado	46	BLR	40.1N	105.1W
College, Fairbanks, Alaska	5*, 13	COL	64.9N	147.8W
Darwin, Australia	65	DAR	12.5S	130.8E
East Grand Forks, Minnesota	13*, 14	GRK	48.0N	97.1W
Fort Myers, Florida	6*, 3	FTM	26.6N	81.9W
Gilmore Creek, Fairbanks, Alaska	49	GIL	65.0N	147.5W
Johannesburg, South Africa	16	JOB	25.9S	27.7E
Kano, Nigeria	53	KNO	12.0N	8.5E
Kauai, Hawaii	37	HAW	22.1N	159.7W
Lima, Peru	6	LIM	11.8S	77.2W
Mojave, California	17	MOJ	35.3N	116.9W
Orroral Valley, Australia	21	RAL	35.6S	149.0E
Ottawa, Canada	3*, 50	OTT	45.4N	75.7W
Prince Albert, Canada	2*, 44	PRI	53.2N	105.9W
Quito, Ecuador	7*, 5	QUI	0.6S	78.6W
Resolute Bay, No. W. Territories	1*, 43	RES	74.7N	95.0W
Rosman, No. Carolina	20	ROS	35.2N	82.9W
St. John's, Newfoundland	4*, 12	NEW	47.6N	52.4W
Santiago, Chile	8*, 8	SNT	33.2S	70.1W
Singapore, Malaysia	11*, 48	SNP	1.3N	103.8E
South Atlantic, Falkland Islands	9*, 38	SOL	51.8S	57.9W
South Point, Hawaiian Islands	15*, 55	SPT	18.9N	155.7W
Stanford, California		STN	34.4N	122.2W
Tananarive, Madagascar	63	MAD	19.0S	47.3E
Tromso, Norway	25	TRO	69.7N	18.9E
University of Alaska, Fairbanks, Alaska	19	ULA	65.0N	147.5W
Winkfield, England	10*, 18*, 15	WNK	51.4N	0.4W
Woomera, Australia	12*, 18	WOO	31.1S	136.8E

\*Indicates station number used prior to July 1965.

Additional information available for the interpretation and use of the ionograms includes log sheets for the rolls of filmed ionograms and refined world maps (Brouwer).

Each film log sheet includes the film number, the date the film was processed, the station name, the pass time, tape number, and qualitative remarks. A list of abbreviations used in the remarks appears in Figure 9.

FIGURE 9  
TERMS USED IN REMARKS ON FILM LOG SHEET

VLF ONLY	- very low freq. transmission only
VLF on	- very low freq. transmission on video
VLF INT.	- very low freq. transmission interference
INT.	- interference
L.L.S.	- loss of line synchronization
L.F.S.	- loss of frame synchronization
L.S.D.	- line synchronization distortion
T.C.R.	- time code rolling
N.T.C.	- no time code
STN.	- station
C.T.O.	- camera turned off
T.S.E.	- tape speed erratic
T.F.	- TELEMETRY FAILURE
d/os	- drop outs
TOBAS	- turned on by another station

The satellite maps are generated from a computer program that computes subsatellite points at specified time intervals of the satellite's orbit. The subsatellite point consists of longitude in degrees  $\pm 180$  deg, geodetic latitude in degrees  $\pm 90$ , and height above sea level in kilometers. The program also computes ascending node crossing for each pass. The Alouette satellite maps include Brouwer elements. The maps are available on rolls of 16-mm microfilm and usually cover periods of about 10 weeks.

The ionograms that are available at NSSDC at the time of publication of this Data Users' Note are given in Figure 10 according to stations and times. A total of 3140 rolls of 35-mm microfilm ionograms are currently available.

FIGURE 10  
IONOGRAM TIMES AND STATIONS

STATION	PASS NUMBER*	PERIOD*					
		START			END		
		MO	DA	YR	MO	DA	YR
Antofagasta, Chile	18 - 4130	09	30	62	07	28	63
College, Alaska, U.S.A.	1 - 17549	09	29	62	04	07	66
East Grand Forks, Minn., U.S.A.	1940 - 16239	02	18	63	01	01	66
Fort Myers, Florida, U.S.A.	12 - 15980	09	30	62	12	13	65
Kano, Nigeria	9625 - 11735	09	03	64	02	05	65
Kauai, Hawaii, U.S.A.	14274 - 16600	08	10	65	01	27	66
Orroral Valley, Australia	15713 - 16480	11	23	65	01	18	66
Ottawa, Ont., Canada	6 - 18009	09	29	62	05	10	66
Port Stanley, Falkland Islands	12 - 16888	09	30	62	02	17	66
Prince Albert, Sask., Canada	13 - 4473	09	30	62	08	23	63
Quito, Ecuador	20 - 16074	09	30	62	12	20	65
Resolute Bay, N.W.T., Canada	7 - 17787	09	29	62	04	24	66
St. John's, Nfld., Canada	11 - 15545	09	30	62	11	11	65
Santiago, Chile	4246 - 16074	08	06	63	12	20	65
Singapore, Malaysia	12 - 16210	09	30	62	12	30	65
South Point, Hawaii, U.S.A.	531 - 13451	11	07	62	06	10	65
University of Alaska, Alaska, U.S.A.	15793 - 15974	11	29	65	12	12	65
Winkfield, England	9 - 15680	09	29	62	11	21	65
Woomera, Australia	18 - 15395	10	01	62	10	31	65

\*Pass numbers and dates are not necessarily inclusive.

B - Alosyn

Investigator

E. L. Hagg - Defence Radio Telecommunications Establishment\*

Tabulations of selected ionospheric parameters were compiled from representative ionograms recorded from September 29, 1962, to January 31, 1964. One horizontal row of tabulation was derived from each selected ionogram. These ionograms were recorded at the following tracking stations:

Resolute Bay, N.W.T., Canada  
College, Alaska, U.S.A.  
Prince Albert, Sask., Canada  
East Grand Forks, Minn., U.S.A.  
Ottawa, Ont., Canada  
St. John's, Nfld., Canada  
Winkfield, England  
South Point, Hawaii, U.S.A.  
Fort Myers, Fla., U.S.A.  
Quito, Ecuador  
Antofagasta, Chile  
Port Stanley, Falkland Islands  
Santiago, Chile  
Woomera, Australia

Figure 11 is a sample of the Alosyn data. The symbols used in the tabulations are the following:

YR	Year
MO	Month
DY	Day of the month
GMT	GMT at which the record was taken, in hours, minutes, and seconds, with the minutes and seconds separated by a solidus. The time given is for $3.0 \pm 1$ sec before the occurrence of the 0.5 Mc/s frequency marker.
LMT	Local mean time in hours and minutes
LONG	Longitude (deg); (+) denotes East
LAT	Latitude (deg); (+) denotes North
HGT	Height of satellite in km
CHI	Solar zenith angle, $\chi$
DIP	Angle of dip of earth's magnetic field at the satellite; (+) denotes North

\*Address: Defence Radio Telecommunications Establishment, Shirley Bay, Ottawa 4, Ontario, Canada.

FIGURE 11  
ALOSYN DATA (DRTE)

YR	MO	UY	GMT	LMT	LONG	LAT	HGT	CHI	DIP	FH	<sup>Y</sup> JFDS	FXS	A Q	FDF2	A Q	JFDF2	FXF2	A Q	FES	Q	G	KP
64	3	3	719/46	318	-60.4	-59.93	105°	104	-56	.72	1.08	1.50	4 0	4.3	3	U	4.09	4.5	3 D	0	1	1+
64	3	3	720/ 3	321	-59.8	-60.83	105°	103	-57	.72	1.08	1.50	4 0	4.0	2	E	4.09	4.5	2 E	0	1	1+
64	3	3	720/18	323	-59.3	-61.62	105°	102	-58	.73	.86	1.30	3 0	4.0	2	E	4.08	4.5	2 E	0	1	1+
64	3	3	720/36	326	-58.6	-62.57	105°	101	-58	.74	.85	1.30	3 0	4.0	3	D	4.08	4.5	2 D	0	2	1+
64	3	3	720/53	329	-57.9	-63.46	105°	100	-59	.75	.79	1.25	2 0	3.8	2	D	3.87	4.3	3 D	0	2	1+
64	3	3	721/11	333	-57.1	-64.40	105°	100	-59	.76	.78	1.25	2 0	3.8	2	D	3.87	4.3	3 D	0	2	1+
64	3	3	822/15	2151	-157.9	79.56	101°	105	85	1.06	.69	1.40	1 0	0	0	0	4.44	5.2	2 E	0	2	1+
64	3	3	822/33	2410	-153.1	79.09	101°	106	85	1.06	.48	1.25	2 0	0	0	0	4.44	5.2	1 G	0	2	1+
64	3	3	822/50	2227	-148.9	78.59	101°	107	85	1.06	.32	1.15	2 G	0	0	0	3.52	4.3	1 H	5.7 D	2	1+
64	3	3	823/ 8	2244	-144.9	77.99	101°	108	85	1.06	.41	1.20	2 G	3.7	2	G	3.67	4.4	1 G	0	2	1+
64	3	3	823/25	2458	-141.4	77.38	101°	109	85	1.06	.20	1.10	2 G	3.7	2	H	3.67	4.4	1 H	0	2	1+
64	3	3	823/43	2311	-138.1	76.68	101°	110	85	1.06	.31	1.15	2 G	3.7	2	G	3.82	4.6	2 D	7.1 D	2	1+
64	3	3	824/ 0	2923	-135.4	75.99	101°	111	85	1.06	.20	1.10	2 G	3.7	2	H	3.82	4.6	1 H	0	2	1+
64	3	3	824/18	2333	-132.7	75.22	101°	111	85	1.07	.40	1.20	2 G	3.8	1	G	3.67	4.4	1 G	0	2	1+
64	3	3	824/35	2443	-130.4	74.4	101°	112	85	1.07	.19	1.10	1 0	3.8	2	H	3.72	4.5	2 H	0	2	1+
64	3	3	824/53	2352	-124.3	73.65	101°	113	85	1.07	0	1.05	1 0	3.7	2	H	3.87	4.7	1 H	0	2	1+
64	3	3	825/10	2359	-126.4	72.86	101°	114	84	1.07	0	1.05	2 D	3.7	2	H	3.82	4.6	1 H	0	2	1+
64	3	3	825/27	6	-124.7	72.05	101°	115	84	1.07	0	1.05	1 0	0	0	0	2.69	3.5	5 H	0	2	1+
64	3	3	825/44	13	-123.2	71.22	101°	116	84	1.07	0	1.05	1 0	3.7	2	H	3.81	4.6	2 H	0	2	1+
64	3	3	826/ 2	19	-121.7	70.34	101°	117	84	1.07	0	1.05	1 D	0	0	0	2.16	3.0	2 H	0	2	1+
64	3	3	826/20	25	-120.4	69.44	101°	117	84	1.07	.68	1.40	4 D	2.2	2	H	2.16	3.0	2 H	0	2	1+
64	3	3	826/37	30	-119.2	68.58	101°	118	84	1.07	.68	1.40	4 D	0	0	0	1.84	2.7	2 D	0	2	1+
64	3	3	826/55	35	-118.0	67.66	101°	119	83	1.07	.68	1.40	4 D	2.0	2	D	1.73	2.6	2 D	0	2	1+
64	3	3	827/12	39	-117.1	66.78	101°	120	83	1.07	.68	1.40	4 D	2.0	2	D	1.73	2.6	2 D	0	2	1+
64	3	3	827/30	43	-116.1	65.95	101°	121	83	1.07	.67	1.40	4 D	2.0	2	D	1.72	2.6	2 D	0	2	1+
64	3	3	827/47	47	-115.2	64.96	101°	122	82	1.07	.67	1.40	4 D	2.0	2	D	1.61	2.5	2 G	4.2 D	2	1+
64	3	3	828/ 5	50	-114.4	64.01	101°	123	82	1.08	.67	1.40	4 D	0	0	0	1.61	2.5	2 G	3.8 D	2	1+
64	3	3	828/22	54	-113.7	63.11	101°	123	82	1.07	.67	1.40	4 D	2.0	2	D	1.99	2.8	1 D	3.8 D	2	1+
64	3	3	828/40	57	-112.9	62.15	101°	124	81	1.07	.54	1.30	4 D	0	0	0	2.15	3.0	2 E	3.8 D	2	1+
64	3	3	828/57	60	-112.3	61.25	101°	125	81	1.07	.54	1.30	4 D	0	0	0	1.61	2.5	2 G	3.8 D	2	1+
64	3	3	829/15	103	-111.7	60.28	101°	126	80	1.07	.80	1.50	4 D	2.5	2	D	2.67	3.5	2 F	4.3 D	3	1+
64	3	3	829/32	105	-111.1	59.36	101°	127	80	1.07	.18	1.10	1 0	2.6	1	D	2.78	3.6	1 D	0	3	1+
64	3	3	830/ 7	110	-110.1	57.47	101°	128	79	1.07	.19	1.10	1 0	0	0	0	2.98	3.8	1 D	0	3	1+
64	3	3	830/24	112	-109.6	56.54	101°	129	79	1.07	.81	1.50	4 0	0	0	0	3.19	4.0	2 D	0	2	1+
64	3	3	830/42	114	-109.1	55.56	101°	130	78	1.06	0	1.05	1 0	0	0	0	2.68	3.5	2 D	0	2	1+
64	3	3	830/59	116	-108.7	54.64	101°	131	78	1.06	.75	1.45	4 D	0	0	0	2.16	3.0	2 E	0	2	1+
64	3	3	831/15	118	-108.3	53.76	101°	131	77	1.06	.81	1.50	4 0	0	0	0	3.39	4.2	1 D	0	3	1+
64	3	3	832/13	126	-107.1	50.57	101°	134	75	1.05	.82	1.50	4 0	0	0	0	1.05	2.0	5 D	0	2	1+
64	3	3	832/31	125	-106.8	49.58	101°	135	75	1.04	.83	1.50	4 0	0	0	0	1.07	2.0	5 E	0	2	1+
64	3	3	832/48	127	-106.5	48.64	101°	135	74	1.04	.26	1.10	1 0	0	0	0	1.19	2.1	1 E	0	2	1+
64	3	3	833/ 6	128	-106.2	47.65	101°	136	73	1.03	.37	1.15	1 0	0	0	0	1.14	2.0	1 E	0	2	1+
64	3	3	833/23	130	-105.9	46.70	101°	137	73	1.03	.46	1.20	1 A	0	0	0	1.65	2.5	5 D	0	2	1+
64	3	3	833/41	131	-105.6	45.71	101°	138	72	1.02	.46	1.20	1 A	0	0	0	1.77	2.6	5 D	0	3	1+
64	3	3	833/58	132	-105.4	44.76	101°	138	71	1.01	.47	1.20	1 A	0	0	0	2.20	3.0	5 E	0	3	1+
64	3	3	834/16	134	-105.1	43.76	101°	139	71	1.01	.40	1.15	1 D	0	0	0	2.20	3.0	5 E	0	2	1+
64	3	3	834/33	135	-104.9	42.82	101°	140	70	1.00	.62	1.30	1 D	3.0	2	A	2.99	3.8	1 A	0	2	1+
64	3	3	834/51	136	-104.7	41.82	101°	140	69	.99	.69	1.35	1 U	3.3	2	D	3.05	3.8	2 F	0	2	1+
64	3	3	835/ 8	137	-104.4	40.87	101°	141	68	.99	.76	1.40	1 A	3.0	2	A	3.06	3.8	2 A	0	2	1+
64	3	3	835/26	139	-104.2	39.87	101°	142	68	.98	.83	1.45	1 D	3.5	2	A	3.47	4.2	1 A	0	2	1+
64	3	3	835/43	140	-104.0	38.92	101°	142	67	.97	.89	1.50	1 A	3.5	2	A	3.48	4.4	2 A	0	3	1+
64	3	3	836/ 0	141	-103.8	37.97	101°	143	66	.96	.90	1.50	1 A	3.5	2	A	3.49	4.4	2 A	0	3	1+
64	3	3	836/18	142	-103.6	36.97	101°	144	65	.95	.91	1.50	1 A	3.7	2	F	3.75	4.6	1 D	0	3	1+
64	3	3	836/35	143	-103.5	36.02	101°	144	65	.95	.91	1.50	1 A	3.8	2	D	3.76	4.6	1 D	0	3	1+
64	3	3	836/53	144	-103.3	35.01	101°	145	64	.94	.98	1.55	1 A	3.5	2	A	3.71	4.4	2 A	0	2	1+
64	3	3	837/10	145	-103.1	34.06	101°	145	63	.93	.98	1.55	1 D	4.0	1	E	3.92	4.6	2 E	0	3	1+
64	3	3	837/28	146	-103.0	33.05	101°	146	62	.92	.99	1.55	1 A	4.0	2	D	3.43	4.5	2 D	0	2	1+
64	3	3	837/45	147	-102.8	32.10	101°	147	61	.91	1.05	1.60	1 A	4.0	2	D	3.84	4.5	2 D	0	2	1+
64	3	3	838/ 3	147	-102.6	31.09	101°	147	60	.90	1.11	1.65	1 A	4.0	2	E	3.85	4.5	2 E	0	3	1+
64	3	3	838/20	148	-102.5	30.14	101°	148	59	.89	1.12	1.65	2 0	3.6	2	E	3.76	4.4	2 E	0	2	1+
64	3	3	838/38	149																		

FH Gyrofrequency at the satellite, in Mc/s. The dip and gyrofrequency are calculated by using the set of 48 spherical harmonic coefficients determined by Jensen and Cain (epoch 1960).  
 JFOS Ordinary wave frequency at the satellite, calculated from the observed Extraordinary wave frequency. That is, JFOS is the plasma frequency at the satellite in Mc/s.  
 FXS Observed Extraordinary wave frequency at the satellite in Mc/s  
 FXS A Accuracy of observation, according to the following code:  
     1. Estimated error less than .025 Mc/s  
     2. Estimated error less than .05 Mc/s  
     3. Estimated error less than .1 Mc/s  
     4. Magnitude of FXS less than tabulated value  
     5. Magnitude of FXS greater than tabulated value  
 FXS Q Quality of the reflection trace near the satellite, according to the following quality table:

	No Spread	Slightly Spread	Moderately Spread	Extremely Spread
Unambiguous records	A	D	G	J
Oblique traces present	B	E	H	K
Cusps and/or forking of the records	C	F	I	L

The classifications of Spread F in this quality table refer to the degree of Spread F at the particular apparent height and frequency at which the parameter was obtained. It is not a classification of Spread F for the ionogram as a whole.

FOF2 Observed Ordinary wave penetration frequency of the F2 layer in Mc/s  
 FOF2 A Accuracy of observation according to the following code:  
     1. Estimated error less than .05 Mc/s  
     2. Estimated error less than .1 Mc/s  
     3. Estimated error less than .2 Mc/s  
     4. Magnitude of FOF2 less than tabulated value  
     5. Magnitude of FOF2 greater than tabulated value  
 FOF2 Q Quality of the reflection trace at the Ordinary wave penetration frequency according to the quality table

JFOF2	Ordinary wave penetration of the F2 layer, calculated from the observed fxF2. The gyrofrequency appropriate to a height of 300 km is used for this calculation.
FXF2	Observed Extraordinary wave penetration of the F2 layer
FXF2 A	Accuracy of observation, according to the FOF2 accuracy code
FXF2 Q	Quality of the reflection trace at the Extraordinary wave penetration frequency, according to the <u>quality table</u>
FES	Maximum frequency of observation of sporadic E
FES Q	Quality of sporadic E, according to the first row of the <u>quality table</u>
G	Strength of signal returned from the earth, according to the following code:
	1. Strong, well-defined echoes
	2. Weak and intermittent echoes
	3. Echoes not observed
KP	3 hourly Magnetic K <sub>p</sub> index

The symbol "-O-" occurring in a column of the tabulations indicates that the parameter was not observed on the ionogram.

It should be noted that one percent of the data recorded at telemetry stations have timing errors greater than 400 sec, and one-fifth percent have timing errors greater than 10 000 sec. Such timing errors can probably be considered systematic over about 30 consecutive ionograms.

#### C - Synoptic Data

##### Investigator

W. Calvert - ITSA\*

Another tabulation has been compiled by ITSA\* for September 29, 1962, to May 30, 1964 (passes 1 - 8318). This listing also includes a partial listing of the ground stations which may have bottomside sounding data to complement the topside data from Alouette 1. The columns in these tabulations are given in Figure 12.

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\*Address: Institute for Telecommunication Sciences and Aeronomy, ESSA, Boulder, Colorado.

FIGURE 12  
DESCRIPTION OF TOPSIDE SOUNDER CATALOG LISTING (ITSA)

**TITLE AND IDENTIFICATION**

S - 27 - Satellite code

DATE - YYMMDD of the first ionogram

DAY OF THE YEAR

UNIVERSAL TIME - HHMM/SS of the first ionogram

PASS NUMBER - Pass number of the first ionogram

TELEMETRY STATION CODE

**SATELLITE DATA**

Frame Number of Ionogram

Correspondence between film and catalog should exist.

The number of frames is approximated from the command schedule (based on a 10-minute readout) and may not correspond with the time and number of frames on the film.

An \* alone denotes data computed at a given special time interval.

No one-to-one correspondence will exist between catalog and film.

UT Universal time (HHMM) at the satellite

LMT Local mean time (HHMM) at the satellite

LT Latitude (deg); (+) denotes North

LN Longitude (deg); (+) denotes East

HT Height above the geoid (km)

FH Gyrofrequency at satellite (Mc/s)

I Dip of magnetic field at satellite (deg); (+) denotes North

X Zenith angle of the sun at the satellite (deg)

GLT Geomagnetic latitude (deg); (+) denotes North

**BOTTOMSIDE GROUND STATION DATA**

Station Code

GND Ground distance from subsatellite point to station (km)

ISO Distance from subsatellite point to isocline passing through station (km); (+) denotes subsatellite point north of isocline

AZ Azimuth of satellite as seen from station (deg)

LMT Local mean time (HHMM) at the station

CHI Zenith angle of the sun at the station (deg)

**GAP**

Denotes re-timing and often corresponds to obvious gaps in the film

The pertinent telemetry stations and their code descriptions are given in Figure 13.

FIGURE 13  
TELEMETRY STATION CODE AND LOCATION (ITSA)

STATION	CODE	STATION LOCATION
BOULDR	Q-19	Boulder, Colorado
BPOINT	P-14	Blossom Point, Maryland
COLEGE	E-05	College, Alaska
FTMYRS	F-06	Fort Myers, Florida
GFORKS	N-13	East Grand Forks, Minnesota
HAWAII	R-15	Naalehu, Hawaii
NEWFLD	D-04	St. John's, Newfoundland
OTTAWA	C-03	Ottawa, Canada
PRINCE	B-02	Prince Albert, Canada
QUITOE	G-07	Quito, Ecuador
RESLUT	A-01	Resolute Bay, Canada
SNPORE	L-11	Singapore, Malaysia
SNTAGO	H-08	Santiago, Chile
SOLANT	J-09	South Atlantic (Falkland Islands)
WNKFLD	K-10	Winkfield, England
WOMERA	M-12	Woomera, Australia

#### D - Electron Density vs Real Height

##### Investigators

G. L. B. Nelms - Defence Research Telecommunications Establishment\*  
G. E. K. Lockwood - Defence Research Telecommunications Establishment\*

These data consist of tabulations of electron (number) density profiles derived from ionograms selected from the period of September 29, 1962, to December 31, 1964. The ionograms were reduced under the assumption that the echoes are received from the area vertically beneath the satellite. When more than one set of reflections was present on the ionogram, the number density was computed from the reflection trace at the shortest apparent range. An exception occurred

\*Address: Defence Research Telecommunications Establishment, Shirley Bay, Ottawa 4, Ontario, Canada.

when the reflections from the earth were found to be associated with the longer range echoes. The ionograms were reduced by the method of laminations<sup>7</sup> using a matrix:

$$p'_i = \sum_{j=2}^{i-1} B_{ij} \Delta h_j$$

$$\Delta h_i = \frac{h_i - h_{i-1}}{B_{ii}}$$

where  $p'_i$  is the virtual range at the wave frequency  $f_i$

$\Delta h_j = |h_j - h_{j-1}|$  and the point  $(f_{xs}, h_{sat})$  is considered point 1

$B_{ij}$  = the average group refractive index, at the wave frequency  $f_i$ , for the lamination from  $h_{j-1}$  to  $h_j$ .

About 20 laminations were used for each trace, with a linear change of plasma frequency with real height assumed within each lamination. The magnetic dip angle and gyrofrequency, which were based upon the 48-term spherical harmonic representation of the earth's magnetic field (Jensen and Cain-epoch 1960), were used to derive the matrix elements  $B_{ij}$ .<sup>8</sup>

For the calculation of the matrix elements for points below the satellite, the gyrofrequency was obtained by means of an inverse cube extrapolation from the value at the satellite. When the Extraordinary trace was used, each wave frequency was converted to an electron density,  $N(h)$ , by using the gyrofrequency determined from the spherical harmonic coefficients evaluated at the height involved.<sup>8</sup>

Figure 14 is a sample of the data held at NSSDC, and the following are the symbols used in the tabulations:

4	The data are $N(h)$ profiles
X or O	X appears when an Extraordinary wave was used O appears when an Ordinary wave was used
T or B	Topside or Bottomside sounder
YR	Year
DAY	Day of the year
GMT	Universal time at which the ionogram was recorded in hours, minutes, and seconds. (The time given is for $3.0 \pm 1$ sec before the occurrence of the 0.5 Mc/s frequency marker.)
LONG	Longitude
LAT	Latitude
CHI	Solar zenith angle, $\chi$
DIP	Angle of dip of the earth's magnetic field at the satellite

FIGURE 14  
ALOUETTE 1 REAL HEIGHT PROFILES (DRTE)

YR	DAY	GMT	LONG	LAT	CHI	DIP	FH	Q	FOF2*	TOTALN		P			
										V	H				
4XT	63 123	2305/ 5	-68.9	-30.29	105	-28	0.51	9	5.36	46.119E11	21				
	1.17	1022.	1.26	984.	1.50	873.	1.76	792.	2.06	732.	2.36	684.			
	3.10	615.	3.50	589.	4.34	550.	5.31	520.	6.39	498.	7.57	479.			
	12.46	427.	16.70	397.	21.46	371.	26.93	345.	33.02	319.	34.31	314.			
												35.49	310.		
4XT	63 123	2305/23	-68.7	-31.30	105	-30	0.51	9	6.26	69.245E11	22				
	1.05	1023.	1.24	924.	1.47	822.	1.73	749.	2.03	694.	2.36	651.			
	3.06	586.	3.46	562.	4.34	525.	5.31	498.	6.39	477.	7.57	459.			
	12.38	410.	16.61	378.	21.46	350.	26.93	321.	32.89	293.	39.58	265.			
												46.90	238.		
													48.44	232.	
4XT	63 123	2305/41	-68.6	-32.30	105	-31	0.52	9	5.31	49.835E11	21				
	1.05	1023.	1.24	923.	1.47	816.	1.73	740.	2.03	684.	2.33	640.			
	3.06	580.	3.46	557.	4.34	522.	5.26	496.	6.33	475.	7.50	458.			
	12.38	409.	16.61	377.	21.46	346.	26.81	316.	32.89	282.	34.18	276.			
												34.83	273.		
4XT	63 123	2305/59	-68.4	-33.31	106	-32	0.52	9	5.31	50.466E11	20				
	1.00	1024.	1.22	879.	1.45	780.	1.70	710.	2.00	657.	2.33	617.			
	3.42	543.	4.29	512.	5.26	486.	6.33	467.	7.50	450.	8.77	434.			
	16.52	361.	21.36	329.	26.81	296.	32.89	264.	34.05	258.	34.83	255.			
4XT	63 123	2306/17	-68.3	-34.32	106	-33	0.53	9	4.95	47.384E11	24				
	1.03	1025.	1.22	887.	1.45	783.	1.70	709.	2.00	656.	2.29	616.			
	3.02	560.	3.42	538.	4.29	507.	5.26	484.	6.33	463.	7.50	446.			
	10.07	414.	11.54	399.	13.10	384.	14.76	369.	16.52	354.	21.36	318.			
												26.70	280.		
												27.86	273.		
4XT	63 123	2306/34	-68.1	-35.27	107	-35	0.53	9	4.15	30.794E11	23				
	0.98	1026.	0.98	1009.	1.19	859.	1.42	759.	1.67	689.	1.97	637.			
	2.61	568.	2.98	544.	3.38	524.	4.24	491.	5.21	469.	6.28	451.			
	8.71	417.	10.07	401.	11.54	385.	13.10	371.	14.76	357.	16.52	342.			
												18.28	327.		
												20.24	312.		
4XT	63 123	2306/52	-67.9	-36.27	107	-36	0.54	9	3.98	30.880E11	22				
	1.22	1027.	1.22	988.	1.45	837.	1.70	750.	1.97	691.	2.29	645.			
	3.02	582.	3.38	559.	4.24	525.	5.21	497.	6.28	473.	7.44	454.			
	10.07	420.	11.54	403.	13.10	387.	14.67	371.	16.43	356.	18.28	338.			
												19.54	329.		
4XT	63 123	2307/10	-67.7	-37.27	107	-37	0.54	9	3.76	24.119E11	23				
	0.94	1027.	0.96	976.	1.17	831.	1.39	732.	1.64	663.	1.94	617.			
	2.57	553.	2.94	531.	3.34	512.	4.20	483.	5.16	460.	6.22	442.			
	6.64	409.	10.00	394.	11.46	381.	13.02	367.	14.67	354.	15.54	347.			
												16.43	339.		
													17.34	330.	
4XT	63 123	2307/28	-67.5	-38.28	108	-38	0.55	9	4.02	44.061E11	23				
	0.94	1028.	0.96	989.	1.14	820.	1.37	717.	1.64	656.	1.91	611.			
	2.57	546.	2.94	524.	3.34	506.	4.20	477.	5.16	454.	6.22	435.			
	6.64	402.	10.00	387.	11.46	373.	12.94	358.	14.59	342.	16.34	325.			
												18.19	304.		
													19.15	292.	
4XT	63 123	2307/46	-67.3	-39.28	108	-39	0.55	9	3.91	41.916E11	23				
	0.94	1029.	0.96	1001.	1.14	834.	1.37	722.	1.61	654.	1.91	607.			
	2.54	545.	2.90	524.	3.29	506.	4.15	478.	5.11	454.	6.17	434.			
	8.58	400.	9.93	383.	11.38	368.	12.94	353.	14.59	337.	16.34	320.			
												17.25	310.		
													18.09	298.	
4XT	63 123	2308/ 3	-67.1	-40.22	108	-40	0.56	9	3.93	38.706E11	24				
	0.94	1030.	0.94	1012.	1.14	837.	1.34	722.	1.61	649.	1.88	603.			
	2.54	538.	2.90	517.	3.29	499.	4.15	471.	5.11	447.	6.17	426.			
	8.58	391.	9.93	376.	11.31	361.	12.86	347.	14.50	333.	16.25	318.			
												17.16	308.		
													18.09	297.	
														18.96	281.
4XT	63 123	2308/21	-66.9	-41.22	108	-41	0.57	9	3.98	42.772E11	23				
	0.98	1031.	1.14	886.	1.34	760.	1.61	677.	1.88	623.	2.19	581.			
	2.90	528.	3.25	510.	4.11	480.	5.06	456.	6.11	435.	7.26	417.			
	9.86	383.	11.31	367.	12.86	351.	14.50	336.	16.25	319.	17.16	310.			
												18.09	301.		
													18.96	286.	
														17.53	243.
4XT	63 123	2308/39	-66.7	-42.22	109	-42	0.57	9	3.88	74.544E11	22				
	0.98	1031.	1.12	875.	1.29	772.	1.47	709.	1.70	664.	1.94	626.			
	2.43	573.	2.72	553.	3.50	512.	4.38	479.	5.36	452.	6.45	429.			
	8.91	390.	10.24	373.	11.69	356.	13.26	340.	14.93	324.	15.80	316.			
												16.70	307.		

FH	Gyrofrequency at the satellite in Mc/s
Q	Quality of the ionogram, according to a code in which 4 refers to best and 9 refers to minimal information. (Use 7 to 9 with caution.) 0 refers to tabulations made before code was established.
FOF2*	The Ordinary wave frequency (in Mc/s) corresponding to the highest number density computed for the ionogram. This is always less than, or equal to, the Ordinary wave penetration frequency of the F layer.
TOTALN	Integral of N, the number of electrons in a column $1\text{ cm}^2$ in horizontal cross section extending from the satellite to the height corresponding to FOF2*. This number is expressed in units of $10^{11}$ electrons per square centimeter column.
P	Number of frequencies used for computing the N(h) profile

In Figure 14, the line which is introduced by symbols such as 4 XT contains the values identified by the symbols, as listed in the previous paragraph. The horizontal lines directly following consist of pairs of numbers representing the electron density and the real height at which the number density occurs, computed for a single ionogram. The first number in each pair is the electron density, expressed in  $10^4$  electrons per  $\text{cm}^3$ . The second number in the pair is the real height expressed in km above the surface of the oblate spheroid which best approximates the surface of the earth. The number density and the height at the satellite are given by the first pair of points for each ionogram. The electron densities listed correspond to the frequencies used for the real height calculation.

The reading errors are such that, for the best quality ionograms, the real heights are reproducible to an accuracy of about one percent. The systematic error introduced by the assumptions on which lamination methods of computation are based has not yet been adequately investigated. Such systematic error in the computed real height is probably less than five percent.<sup>8</sup>

One percent of data recorded at telemetry stations have timing errors greater than 400 sec; one-fifth percent have time errors greater than 10 000 sec. Such timing errors will probably be systematic over 30 consecutive ionograms.<sup>8</sup>

## E - Electron Density Profiles

### Investigators

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The Institute for Telecommunication Sciences and Aeronomy (ITSA) in the United States and the Radio and Space Research Station (RSRS) of the Science Research Council in England used selected ionograms to make electron density profiles of the ionosphere. The Radio and Space Research Station selected ionograms from the passes indicated by an asterisk at the Port Stanley and Singapore tracking stations, while ITSA selected ionograms from all the other tracking stations shown in Figure 15.

The ionograms were converted to curves showing the electron density as a function of height. This was accomplished by the reduction of the Extraordinary trace with the method of laminations described in Section D.<sup>9</sup>

Figure 16 is a sample of the RSRS data. The universal time is given in hours, minutes, and seconds for the time when the sounder frequency was 2.0 Mc/s. The electron densities, listed at 10-km intervals of real height, are multiplied by  $10^{-5}$  and given in electrons per  $\text{cm}^3$ . The plot in Figure 16 shows the variation of electron density with geopotential height,  $H'$ , where  $1/H' = 1/h + 1/R$  and R represents the mean radius of the earth.

The electron density profiles produced by CRPL are in the form of computer plots and listings. The real height is plotted against the electron density (i.e., plasma frequency) on semilogarithmic paper. The computer listing for each reduced ionogram includes the following:

1. Indication of the type of trace — Extraordinary or Ordinary
2. Magnetic dip angle and gyrofrequency at the satellite
3. Latitude, longitude, and height of the satellite
4. Date and universal time
5. Date and place of reduction

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FIGURE 15

## STATIONS AND TIMES FOR SELECTED IONOGRAMS (ITSA, RSRS)

Station/Pass No.	Date Mo Da Yr	Begin Time (UT)	Station/Pass No.	Date Mo Da Yr	Begin Time (UT)
Antofagasta, Chile			Ottawa (Cont'd)		
26	10 01 62	0408	2577	04 06 63	0228
100	10 06 62	1450	2598	04 07 63	1448
1823	02 09 63	2114	2672	04 13 63	0152
1864	02 12 63	2126	2903	04 27 63	2340
1877	02 13 63	2010	2911	04 28 63	1320
1891	02 14 63	2049	2916	04 28 63	2236
1918	02 16 63	2017	2924	04 29 63	1212
1932	02 17 63	2053	2938	04 30 63	1254
1959	02 19 63	2025	3066	05 09 63	2228
2081	02 28 63	1859	3907	07 10 63	1331
2597	04 07 63	1428	Port Stanley, Falkland Islands		
3527	06 14 63	1732	370	10 26 62	0930
3568	06 17 63	1741	588	11 11 62	0856
Blossom Point, Maryland, U.S.A.			609	11 12 62	2140
501	11 04 62	2307	* 1626	01 26 63	1012
989	12 10 62	1728	* 1660	01 28 63	2221
1933	02 17 63	2112	* 1667	01 29 63	1017
2096	03 01 63	1957	1817	02 09 63	1006
2191	03 08 63	1902	* 1836	02 10 63	1953
2286	03 15 63	1808	Quito, Ecuador		
2571	04 05 63	1522	26	10 01 62	0355
2787	04 19 63	1245	623	11 13 62	2153
2957	05 03 63	2240	637	11 14 62	2231
College, Alaska, U.S.A.			650	11 15 62	2122
26	10 01 62	0335	677	11 17 62	2048
472	11 02 62	1952	691	11 18 62	2129
503	11 05 62	0238	1342	01 05 63	1434
542	11 07 62	2304	1932	02 17 63	2103
553	11 08 62	1815	2041	02 25 63	2041
579	11 10 62	1557	2597	04 07 63	1438
850	11 30 62	1237	3527	06 14 63	1722
1465	01 14 63	1425	3568	06 17 63	1728
Fort Myers, Florida, U.S.A.			4375	08 15 63	2139
26	10 01 62	0348	4565	08 29 63	1950
Ottawa, Ont., Canada			4592	08 31 63	1919
26	10 01 62	0337	4613	09 02 63	0729
1464	01 14 63	1255	6133	12 22 63	1640
1817	02 09 63	0944	7441	03 27 64	1545
2218	03 10 63	1833	7463	03 29 64	0355
			7510	04 01 64	1521
			7530	04 03 64	0330
			7536	04 03 64	1449

FIGURE 15 (CONT'D)  
STATIONS AND TIMES FOR SELECTED IONOGRAMS (ITSA, RSRS)

Station/Pass No.	Date Mo Da Yr	Begin Time (UT)	Station/Pass No.	Date Mo Da Yr	Begin Time (UT)
Quito (Cont'd)			Santiago (Cont'd)		
7604	04 08 64	1425	8291	05 28 64	2011
7632	04 10 64	1355	8549	06 16 64	1757
7653	04 12 64	0203	8576	06 18 64	1725
8196	05 21 64	2104	8644	06 23 64	1702
8223	05 23 64	2026	8671	06 25 64	1630
8277	05 27 64	1932	8766	07 02 64	1535
8291	05 28 64	2002	8834	07 07 64	1511
8481	06 11 64	1818	9641	09 04 64	1905
8549	06 16 64	1754	10191	10 15 64	0144
8644	06 23 64	1659	10211	10 16 64	1334
8671	06 25 64	1628	10666	11 18 64	2111
8739	06 30 64	1603	10761	11 25 64	2012
8766	07 02 64	1532	10951	12 09 64	1822
8834	07 07 64	1506	11114	12 21 64	1701
8861	07 09 64	1436	11141	12 23 64	1631
8956	07 16 64	1334	11703	02 02 65	2138
9044	07 23 64	0114	11704	02 02 65	2318
9641	09 04 64	1910	12681	04 15 65	1338
9654	09 05 64	1810	12702	04 17 65	0155
10191	10 15 64	0142	12708	04 17 65	1304
10204	10 16 64	0035	13557	06 18 65	1734
10211	10 16 64	1339	Singapore, Malaysia		
10666	11 18 64	2100	643	11 15 62	0902
10679	11 19 64	1958	657	11 16 62	0941
10951	12 09 64	1821	670	11 17 62	0832
10964	12 10 64	1711	684	11 18 62	0909
10978	12 11 64	1743	* 792	11 26 62	0707
11704	02 02 65	2324	* 1952	02 19 63	0811
12681	04 15 65	1340	* 2292	03 16 63	0609
12702	04 17 65	0143	* 2346	03 20 63	0508
12708	04 17 65	1310	* 2414	03 25 63	0443
13557	06 18 65	1724	* 2706	04 15 63	1323
13563	06 19 65	0455	* 2801	04 22 63	1228
Resolute Bay, N.W.T., Canada			* 4164	07 31 63	1034
26	10 01 62	0332	South Point, Hawaii, U.S.A.		
2598	04 07 63	1458	612	11 13 62	0226
Santiago, Chile			626	11 14 62	0304
4375	08 15 63	2133	639	11 15 62	0155
7510	04 01 64	1519	653	11 16 62	0233
7632	04 10 64	1352	666	11 17 62	0131
8196	05 21 64	2106	680	11 18 62	0203
8223	05 23 64	2036			

FIGURE 16

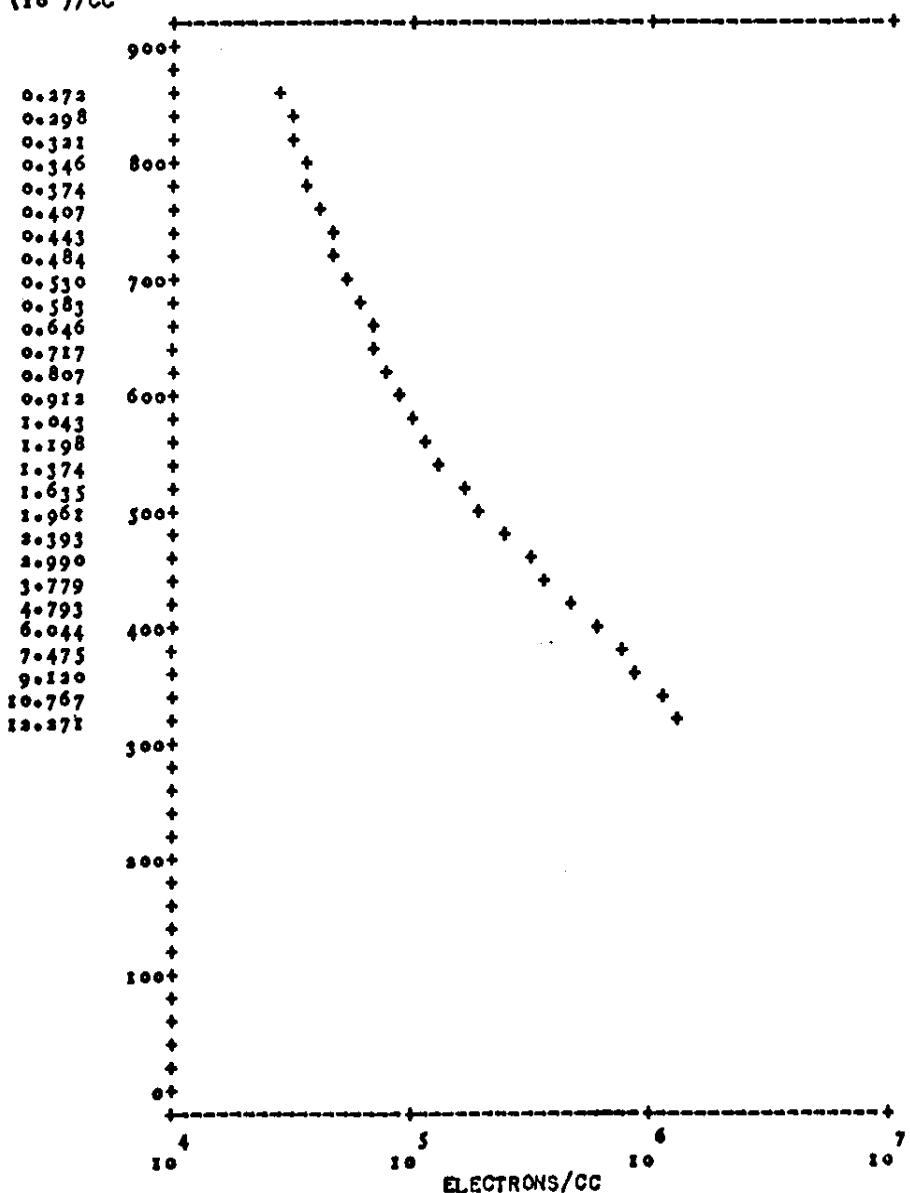
## SAMPLE OF RSRS DATA

SINGAPORE 26 NOV 1963 REV 792 FRAME 39

0715+40 UT 4117+5 LONG -13+8 LAT

HT 0 10 20 30 40 50 60 70 80 90

HT	0	10	20	30	40	50	60	70	80	90
1000	0.365									
900	0.362	0.351	0.341	0.331	0.322	0.313	0.304	0.296	0.287	0.277
800	0.304	0.487	0.469	0.453	0.438	0.424	0.410	0.397	0.385	0.373
700	0.757	0.721	0.693	0.664	0.636	0.609	0.586	0.563	0.543	0.523
600	1.294	1.225	1.159	1.094	1.031	0.970	0.933	0.877	0.833	0.795
500	2.860	2.608	2.372	2.173	2.004	1.841	1.707	1.592	1.481	1.374
400	7.762	7.081	6.444	5.858	5.299	4.774	4.398	3.880	3.501	3.171
300					35.70	22.08	11.43	10.71	9.975	9.238

N GEOPOTENTIAL  
HEIGHT  
( $10^5$ ) / CC

6. Receiving station, pass number, and frame number
7. Digitization of the measured frequency vs virtual height
8. Tabulation of electron density and the corresponding altitude
9. FOF2 – the Ordinary wave frequency corresponding to the highest density computed for the ionogram
10. TOTALN – the number of electrons in a column 1 cm<sup>2</sup> in horizontal cross section extending from the satellite to the height of reflection corresponding to the FOF2
11. The scale height
12. Tabulation of interpolated values of electron density at fixed heights
13. Tabulation of interpolated values of height at fixed electron densities

#### F – Electron Density and Scale Height vs Real Height

##### Investigators

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 K-L. Chan – Ames Research Center\*\*\*

Six volumes of data are available; they consist of tabulations and/or graphs of electron density vs real height and scale height vs real height. Scale height, H, is defined by

$$H = \frac{-N}{\frac{dN}{dh}}$$

where N is the electron density and h is the real height.

The data included in one volume were computed from Alouette 1 ionograms recorded at Stanford University. These ionograms were recorded during the periods of May 1 to July 23, 1963, and November 1, 1963, to January 28, 1964. Plots of average electron density versus dip latitude, and average scale height versus dip latitude, are included.

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Another volume contains data computed from all Alouette 1 ionograms recorded at South Point, Hawaii. These ionograms were recorded during the months of November and December 1962, and May, June, October, and November 1963. Graphs of average electron density and average scale height versus local time and dip latitude are also included.

A series of four volumes contains data chosen primarily for nearly complete latitudinal coverage over the American continents during an epoch of solar minimum. The ionograms were recorded at the following tracking stations, which are listed with their codes:

Antofagasta, Chile	AGASTA
College, Alaska, U.S.A.	COLEGE
Fort Myers, Fla., U.S.A.	FTMYRS
East Grand Forks, Minn., U.S.A.	GFORKS
Ottawa, Ont., Canada	OTTAWA
Prince Albert, Sask., Canada	PRINCE
Quito, Ecuador	QUITOE
Resolute Bay, N.W.T., Canada	RESLUT
South Atlantic Station (U.K.)	SOLANT
St. John's, Nfld., Canada	STJOHN

The first of these four volumes covers the period from November 1, 1962, to January 29, 1963; the second covers the periods from March 1 to March 31 and from May 3 to May 31, 1963; and the third covers the periods June 1 to July 31, from September 1 to September 30, and the day of October 31, 1963. The fourth volume of the series contains the summary graphs of electron density and scale height for the data presented in the first three volumes. The graphs are grouped into three main categories:

1. Variations along the individual satellite orbits
2. Latitudinal variations of the seasonal average at fixed altitudes vs local time
3. Diurnal variations of the seasonal average at fixed altitudes vs dip latitude

The data in all six volumes were reduced by the method of overlapping polynomials. Details of this method of reduction are given in references 1 and 7. The computations were based upon digitizations of the leading edge of the ionograms. The number of points used varied from 8 for smooth traces to 20 or more for curves with severe cusps.<sup>1</sup>

The reduction method assumed that, over small ranges of plasma frequency, the real height profile can be approximated by a polynomial,

$$\Delta h = \sum_{j=1}^n \alpha_j (f_N - f_{N_s})^j$$

where  $f_{N_s}$  is the plasma frequency at the satellite and  $n$  is the number of points to which the polynomial was fit. Since several polynomials were used over a series of small frequency ranges, a polynomial representing the exact shape near the designated frequency only was required when the real depth was calculated. The polynomial was chosen to give the correct virtual depth at frequencies just above and below, as well as at the frequency under consideration. The polynomial was also joined to an already determined part of the curve, so that a smooth continuation of the real depth curve with the correct gradient is assured. The coefficients,  $\alpha_j$ , were evaluated by using the known real depths and the integral relation between virtual and real height.<sup>1,7</sup>

Since this procedure required known values, the previously described technique of laminations was used for the section of the trace near the satellite. Both  $f_{x_s}$  and  $f_h$  at the satellite were needed because the method of laminations started with the plasma frequency for that position. The required positional data were obtained by linear interpolation of the orbital information listed at 1-min intervals in the Alouette 1 World Maps of the Goddard Space Flight Center. The 48-term spherical harmonic expansion of the earth's magnetic field (Jensen and Cain, epoch 1960) was then used to calculate the gyrofrequency at the satellite. Since the gyrofrequency was a function of height, an inverse cube approximation was applied to obtain the gyrofrequency for a given real height. This value was used to get the plasma frequency and, hence, the electron density.<sup>1</sup>

Possible sources of error were the digitization of the ionograms, the location of the zero range frequency, and the use of linear interpolations in evaluating positions. For a good ionogram, the height at which a given electron density was found is probably correct to  $\pm 10$  kilometers. The accuracy increases with an increase in height. Scale heights are probably correct to  $\pm 10$  percent at heights below 800 km, and the accuracy decreases with increasing height.<sup>10</sup>

Data users are further cautioned that, in the reduction from ionograms to electron density profiles, the radio signals were always assumed to be propagated vertically beneath the satellite. Any error introduced by this assumption is a function of how far the signal deviated from the vertical path. This error, if any, cannot be readily estimated unless a complicated computer program of ray tracing is used. The scale height data were computed from the vertical

electron density profiles. If the scale height of interest is along a magnetic field line, the value of the scale height in the volumes has to be modified. The method for accomplishing this is illustrated in references 4 and 11 and is especially needed for the low latitudinal region.

A sample of the data appears in Figure 17. The symbols and units appearing in the tabulations are as follows:

N	Electron density, $10^5$ per $\text{cm}^3$
h	Real height above the ground, km
Pass	Pass number of Alouette 1
UT	Universal time for the occurrence of the frequency at which the Extraordinary trace had zero range for the particular ionogram
Date	Given as XX XX XX year, month, day; all zeros are suppressed
Time	Given as XX XX XX hour, minute, second; all zero digits on extreme left are suppressed
LONG	Geographic longitude, deg; positive longitude is east of Greenwich, and negative is west of Greenwich
LAT	Geographic latitude, deg; positive indicates northern latitude, and negative indicates southern latitude
QUAL	Quality factor for the ionogram, coded in two-digit numbers (11, 21, 31, 12, 22, 32, 13, 23, and 33) and defined as follows: First Digit <ol style="list-style-type: none"> <li>1. Excellent quality ionogram. Extraordinary trace is narrow, of high contrast, easily identifiable, possesses only small gaps, and cannot be confused with Ordinary trace, spreading or resonances anywhere along its extent. No spurious responses.</li> <li>2. Good quality ionogram. Extraordinary trace is not too spread, of good contrast, fairly easily identifiable along most of its extent; any large gaps are easily interpolated, and no major confusion exists with the Ordinary trace, spreading or resonances, or spurious responses.</li> <li>3. Poor quality ionogram, but readable. Considerable spreading, lack of contrast, overlapping traces and resonances, spurious traces, etc., which cause somewhat questionable scaling accuracies.</li> </ol>

FIGURE 17  
SAMPLE OF ELECTRON DENSITY  
AND SCALE HEIGHT DATA VS REAL HEIGHT (ARC)

PASS 2164 AT OTTAWA, 63 3 6								
HEIGHT	ELECTRON DENSITY IN ELECTRONS PER CC (X10-5)							
	193201	193236	193311	193346	193421	193456	193531	193606
1000	0.160	0.162	0.150	0.149	0.153	0.146	0.134	0.130
950	0.181	0.186	0.168	0.170	0.173	0.166	0.152	0.150
900	0.206	0.212	0.194	0.194	0.198	0.191	0.176	0.174
850	0.236	0.241	0.222	0.223	0.226	0.220	0.203	0.201
800	0.271	0.279	0.257	0.257	0.260	0.253	0.234	0.232
750	0.320	0.328	0.306	0.304	0.308	0.300	0.279	0.275
700	0.386	0.389	0.366	0.362	0.367	0.358	0.332	0.328
650	0.469	0.471	0.441	0.438	0.437	0.427	0.395	0.399
600	0.583	0.588	0.546	0.537	0.544	0.529	0.492	0.495
550	0.748	0.759	0.703	0.701	0.688	0.676	0.617	0.642
500	0.998	1.013	0.938	0.920	0.921	0.903	0.826	0.851
450	1.383	1.411	1.292	1.260	1.279	1.240	1.129	1.163
400	1.964	2.014	1.841	1.769	1.826	1.757	1.593	1.651
350	2.842	2.954	2.735	2.583	2.661	2.577	2.344	2.438
300	4.219	4.325	4.140	3.925	3.993	3.803	3.531	3.708
HEIGHT	SCALE HEIGHT, KM							
950	384.1	372.4	394.7	361.3	387.2	374.2	370.5	335.1
900	366.2	371.2	358.0	359.9	366.4	351.2	346.9	334.4
850	346.5	348.0	334.5	342.0	344.0	335.2	330.6	326.3
800	326.8	326.0	313.8	323.8	322.8	319.2	314.4	317.7
750	301.9	305.3	298.0	304.0	305.4	303.0	298.9	296.1
700	274.4	284.6	282.1	284.1	288.0	286.8	283.3	274.5
650	246.9	256.5	260.7	252.6	270.5	268.7	267.5	246.6
600	219.6	219.8	221.0	213.1	230.9	225.4	232.9	214.7
550	192.1	189.8	192.5	197.0	195.0	194.1	199.8	194.0
500	166.2	165.5	172.0	181.0	170.1	175.0	176.4	177.7
450	153.5	149.2	153.2	159.7	150.1	154.6	156.5	157.7
400	138.7	135.9	132.9	138.6	135.2	135.5	137.6	134.1
350	128.8	129.6	123.1	125.8	128.3	129.6	124.9	124.7
300	138.7	145.8	125.3	125.3	127.9	129.9	130.4	125.9
LONG	-79.72	-79.33	-78.93	-78.50	-78.03	-77.53	-76.95	-76.35
LAT	36.41	38.35	40.30	42.24	44.18	46.11	48.03	49.96
QUAL	13	13	13	13	13	13	13	13

Second Digit

1.  $f_x F_2$  clearly visible and read.
2.  $f_x F_2$  not quite visible, but highest visible frequency close to  $f_x F_2$  or presence of ground reflections would allow an estimate of  $f_x F_2$ .
3.  $f_x F_2$  not visible.

The volume of data from Hawaii has the following additional parameters:

SPOINT	Tracking station at South Point, Hawaii
SAT	Electron density at the altitude of the satellite
NT	Integrated electron density in units of $10^{13}$ per cm <sup>2</sup>
HS	Satellite altitude in km
DIPL	Magnetic dip latitude, deg; positive sign indicates northern magnetic latitude, and negative sign indicates southern magnetic latitude
INVL	Magnetic invariant latitude in deg
L	Magnetic L shell number
DIP	Magnetic dip angle in deg; positive sign indicates northern magnetic latitude, and negative sign indicates southern magnetic latitude
FHS	Electron gyrofrequency at the satellite in Mc/s
KP	Planetary magnetic activity index
SNL	Sunlight indicator; 1 = satellite solar illuminated 0 = satellite not solar illuminated

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40F14040F540F6F440F3F3F94040F740F84040F240F4F4	REC	109, LENGTH	23
40F14040F540F6F440F3F4F04040F64CF34040F040F2F5	REC	110, LENGTH	23

LAST FEW	RECORDS OF FILE 1	REC	1. LENGTH	23
	REC	2. LENGTH	23	
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40F44040F540F7F240F1F7F34040F1F1F04040F040F1F7	REC	5. LENGTH	23	
40F44040F540F7F240F1F7F34040F1F1F04040F040F1F8	REC	6. LENGTH	23	
40F44040F540F7F240F1F7F34040F1F1F5F64040F040F5F8	REC	7. LENGTH	23	
40F440F4F840F7F14040FSF940F1F2F1FC4040F04040F4	REC	8. LENGTH	23	
40F440F4F840F7F140F1F0F140F1F1F3F14040F04040F5F8	REC	9. LENGTH	23	
40F440F4F840F7F140F1F0F240F1F1F5F74040F040F5F4	REC	10. LENGTH	23	
40F440F4F840F7F140F1F0F340F1F0F4FC4C4040F140F3F9	REC	11. LENGTH	23	
40F440F4F840F7F140F1F0F440F1F1F1F84040F040F4F0	REC	12. LENGTH	23	
40F440F4F840F7F140F1F0F740F1F1F1F74040CF040F4F0	REC	13. LENGTH	23	
40F440F4F840F7F140F1F0F940F1F0F3F94040F040F3F9	REC	14. LENGTH	23	
,0F440F4F840F7F140F1F1F240F1F0F3F94040CF040F3F9	REC	15. LENGTH	23	
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40F440F4F840F7F140F1F1F440F1F040F0404CF340F4F0	REC	17. LENGTH	23	
40F440F4F840F7F140F1F1F740F1F040F24040F040F4F1	REC	18. LENGTH	23	
40F440F4F840F7F140F1F1F840F1F0F3F84040CF040F3F7	REC	19. LENGTH	23	
40F440F4F840F7F140F1F2F040F1F040F04040F040F3F9	REC	20. LENGTH	23	
40F440F4F840F7F140F1F2F5404CF9F2F1404CF040F4F3	REC	21. LENGTH	23	
40F440F4F840F7F140F1F2F84040F9F2F14040F040F2F0	REC	22. LENGTH	23	
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40F440F4F840F7F140F1F3F34040F8F4F2404CF040F2F2	REC	25. LENGTH	23	
40F440F4F840F7F140F1F4F14040F8F4F24040F040F2F1	REC	26. LENGTH	23	
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40F440F4F840F7F140F1F4F74040F840F2404CF040F2F1	REC	30. LENGTH	23	
40F440F4F840F7F140F1F5F84040F5F3F24040F040F2F9	REC	31. LENGTH	23	
	REC	32. LENGTH	23	
	REC	33. LENGTH	23	

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40F440F4F840F7F140F2F1F14040F2F5F1F14040F540F3F5	REC	52,	LENGTH	23
40F440F4F840F7F140F2F1F14040F1F5F1F14040F540F3F5	REC	53,	LENGTH	23
	REC	54,	LENGTH	23